12

TARDEC

Technical Report

No. 13613

Evaluation of Commercial Water-In-Fuel Test Kits

December 1994

By William R. Williams
Chris Keehan
USA Tank Automotive Command
Mobility Technology Center Belvoir

U.S. Army Tank-Automotive Command
Research, Development and Engineering Center
Warren, Michigan 48397-5000

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
December 1994

3. REPORT TYPE AND DATES COVERED
Final

4. TITLE AND SUBTITLE
Evaluation of Commercial
Water-In-Fuel Test Kits

5. FUNDING NUMBERS
TA

6. AUTHOR(S)
William R. Williams
Chris Keehan

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
USA TANK AUTOMOTIVE COMD
MOBILITY TECH CTR BELVOIR
ATTN AMSTA RBF
10101 GRIDLEY ROAD STE 128
FORT BELVOIR VA 22060-5843

8. PERFORMING ORGANIZATION REPORT NUMBER
TARDEC-TR-13613

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
CDR ARMY QM SCHOOL
ATTN ATSM CD
FT LEE VA 23801-5000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Distribution unlimited; approved for public release.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report describes evaluation tests on four commercial water-in-fuel test kits intended to measure the level of free water in aircraft fuels. Evaluations were conducted using water saturated fuel deliberately contaminated with predetermined levels of free water. The readings of the test kits were compared to determine the test kit that is most appropriate for Army use.

14. SUBJECT TERMS
Water/fuel Characteristics, Water/oil Characteristics, Test Kits, Aircraft Fuels, Refueling Operations

15. NUMBER OF PAGES 30

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

No. 13613

Evaluation of Commercial Water-In-Fuel Test Kits

Accesion For		
NTIS CRA&I		☒
DTIC TAB		☐
Unannounced		☐
Justification		
By		
Distribution /		
Availability Codes		
Dist	Avail and / or Special	
A-1		

December 1994

By William R. Williams
Chris Keehan
USA Tank Automotive Command
Mobility Technology Center Belvoir
Fuels and Lubricants Division

Contents

Figures

Tables

Appendix

Section 1 Introduction

OBJECTIVE

This report describes the evaluation of four commercial test kits designed to measure the level of free water in aviation fuels.

BACKGROUND

The Army is required to daily test aircraft fuel for levels of free (i.e., undissolved) water at the refueling site as set forth in FM 10-68. Regulations require that aircraft fuels exhibit no higher than 10 parts per million (ppm) free water at the skin of the aircraft. Presently, the Army uses the Gammon Aqua-Glo as a field means to detect free water in fuel. The Army Quartermaster School considered the Aqua-Glo too expensive to procure and operate and requested this Center evaluate the Shell Water Detector Kit as a possible alterative. A market search revealed two other candidate test devices: the Exxon Hydrokit and the TMI Accumetric contamination monitor. These four instruments were selected and included in the test plan.

Section 2 Investigation

TEST ITEMS

The four test items are described below based on manufacturer's literature and observation. Salient features are shown in Table 1.

Table 1. Salient Features of Test Kits

	GAMMON AQUA-GLO	TMI ACCUMETRIC	SHELL WATER DETECTOR	EXXON HYDROKIT
Test kit package size, cm	25 x 33 x 25.5	41.5 x 15.25 x 34.25	10 x 9 x 3.5	27 x 19 x 12
Calibration standard included	yes	yes	no	no
Tests per package	25	25	80	100
Fuel sample size req'd, mL	500 for 1 to 12 ppm, 100 for > 12 ppm	450	~20	~40
Power requirements	110 vac or built-in NiCd battery	110 vac or built-in NiCd battery	N/A	N/A
Shelf Life of expendables	not stated	not stated	6 months	18 months
Effect of additives	unknown	unknown	*	unknown
Detection levels, ppm	1 to 60	0 to ?	≥30 (GO/NOGO)	>30 (GO/NOGO)

** Response purported to be affected with turbine fuel containing corrosion inhibitors other that HITEC E-515.*

Gammon Aqua-Glo

The Aqua-Glo has been used for many years by the Army. Its use is mandated under FM 10-68, *Aircraft Refueling*. The other services use a modified militarized version. In addition, the Aqua-Glo is used in many commercial airports around the world. The method is covered by ASTM D 3240 and is generally considered the standard test method for free water in aviation fuel. The Aqua-Glo consists of a pad holder that is intended to be installed on a pressurized fuel stream plus the measuring instrument. It utilizes expendable pads coated on one side with an uranine (sodium fluorescein) dye that fluoresces a bright yellow when illuminated by ultra-violet (u.v.) light after exposure to free (i.e., undissolved) water. The pad (25 mm dia.) is installed in the holder to allow a predetermined quantity of fuel to pass through it. The pad is then installed in the instrument and subjected to u.v. The amount of fluorescence indicates the amount of water in the fuel. The fluorescence level on the test pad is measured by comparison to a standard that is mounted in the Aqua-Glo instrument. A camera type shutter regulates the amount of u.v. light to the standard until the two pads (test and standard) indicate the same light levels as measured by matched photocells. The shutter position is shown on a scale reading 1 to 12 which indicates parts per million (ppm) water for a fuel sample of 500 mL. For water levels greater than 12, a smaller fuel sample size is used and the results multiplied accordingly. The pads are marketed by Gammon and one other company, Astrodyne. However, all the pads used in this test program were marketed by Gammon. The pads come with no expiration date but did carry the manufacturing date. The Aqua-Glo is powered by 110 v.a.c or by a built-in rechargeable battery. All parts come in a lightweight fiberboard case making the unit relatively durable. With the case the unit weighs approximately 15 Kg (7 pounds). The Aqua-Glo is especially appropriate to Army use as it is most accurate in the maximum water level allowable for aircraft refueling operations.

TMI Accumetric

The TMI Accumetric is a comparatively new design that is currently being evaluated by an ASTM Task Force under Committee D-2. The instrument can also measure solid contaminants by means of light absorbance but this feature was not evaluated in this study. It utilizes pads similar to those used in the Aqua-Glo but larger diameter (37 mm as opposed to 25 mm). The pads that came with the instrument were manufactured by Gammon. The Accumetric works similar to the Aqua-Glo with a calibration standard included. Normal test calls for a sample size of 450 mL. The operation is essentially automatic with the output in digital format with no apparent upper limit. The digital readout makes it a little more user friendly than the Aqua-Glo. It is powered by 110 v.a.c. or by built-in rechargeable battery. It is housed in a lightweight fiberboard case that appears to be highly durable. The total weight is approximately 25 Kg (11 pounds). Its cost is approximately twice that of the Aqua-Glo.

Shell Water Detector Kit

The Shell Kit is marketed by Gammon. It is supposedly used by many commercial airports but none could be found in the Washington area. It is essentially a go, no-go type test with a distinct indication for water at 30 ppm water or higher, the commercial standard. It uses a small paper membrane treated with water sensitive chemicals. The membrane is protected by a plastic capsule that fits on the end of a syringe. The capsule containing the membrane is expendable. Five mL of fuel are drawn through the capsule and a color change from yellow to green indicates a water level of 30 ppm or greater. One problem with the Shell kit is that it states on the label that: "Response to free water may be affected with Jet Fuel containing inhibitors other than Hitech E-515 (Santolene C)." Hitech [sic] E-515 is no longer listed on the Air Force Qualified Products List (QPL) for corrosion inhibitors. We received our sample Shell Kit in July 1993 and it indicated an expiration date of December 1993, thus the shelf life is relatively short. The Kit comes with 80 capsules packed in ten metal tubes; the syringe is ordered separately. The Shell Kit, manufactured in England, is cheap, lightweight and easy to use. However, it is obviously not intended to work in the region that the Army requires (10 ppm).

Exxon Hydrokit

The Exxon Hydrokit is manufactured by Velcon Filters, Inc. It was originally developed under Exxon sponsorship but since then Exxon has relinquished all rights and future kits will be called Velcon Hydrokit. Significantly, Exxon included a Disclaimer of Warranties within the Hydrokit package. The Hydrokit uses expendable tubes filled with a white powder consisting of calcium carbonate treated with an organic dye. Rubber grommets on the top of each tube are intended to be pierced by a needle whose other end is submerged in the test fuel. The tubes possess a partial vacuum that allows the fuel to be literally sucked in. The tube is shaken and the powder at the bottom of the tube is intended to turn color when the water level in the fuel is greater than 30. The color change is from buff to a washed out pink and cannot be considered very distinct. The kit as ordered came with one hundred prefilled tube to a box that also included two tube holders with needles, four extra needles and two 150 mL sample bottles. We received our Hydrokit in July 1993 and it indication an expiration date of January 1995 showing a longer shelf life than the Shell kit. The Hydrokit is cheap, lightweight and easy to use but not always easy to read. Like the Shell kit, it is not very appropriate for the range that the Army uses.

TEST FUEL

Turbine fuel JP-8 meeting the requirements of MIL-T-83133 was used for all tests. This fuel is practically identical to commercial Jet A-1 (ASTM D 1655) except for the presence of the military fuel additives. Because the Shell Kit was assumed to be sensitive to the type of corrosion inhibitor it was decided to test each device with separate fuel batches each containing one of the twelve corrosion inhibitors listed on Air Force QPL-25017-17. To accomplish this, the JP-8 was stripped of its additives by clay filtration then new additives were mixed-in accordingly. Test fuel analysis is shown in Table 2.

Table 2. Properties of Test Fuel, JP-8

TEST PROPERTY	ASTM METHOD	SPEC LIMIT	RESULTS
Color	–	–	light straw
TAN, mg KOH/gm	D974	0.015 max	0.011
Distillation, °C	D2887		
IBP		report	173.2
10%		205 max	185.0
20%		report	193.7
50%		report	209.8
70%		report	240.4
EP		300 max	263.6
Residue, %		1.5 max	1.5
Loss, %		1.5 max	1.5
Flash Point, °C	D93	38 min	58
Gravity, API @ 60°F	D1298	37.0 to 51.0	42.7
Existent gum, mg/100mL	D381	7.0 max	2.0
Particulate matter, mg/L	D2276	1.0 max	0.0*
Fuel system icing inhibitor, vol%	D5006	0.10 to 0.15	0.15*
Water reaction interface rating	D3948	1b max	1b
Fuel electrical conductivity, pS/m	D2624	150 to 600	261*

** Indicates value measured after clay filtration and redoping with additives*

APPROACH

Fuel was clay filtered and then redoped. Each of the four test devices was tested with twelve different batches of fuel initially at four different water levels. The fuel was water saturated before the addition of free water.

a. Sufficient quantity (approximately 100 L) of JP-8 was obtained. It was evaluated to ensure that it met the requirements of MIL-T-83133 (see Table 2).

b. Fuel System Icing Inhibitor (FSII)/Diethylene Glycol Monomethyl Ether, Static Dissipator Additive (SDA) and one of each type of Corrosion Inhibitor/Lubricity Improver listed on the Air Force QPL-25017-17 (see Table 3) were obtained.

c. The JP-8 was clay filtered to remove all additives (see Appendix A).

d. Fuel System Icing Inhibitor (FSII) was added at 0.15% and Static Dissipator Additive (SDA) is added in sufficient levels (approximately 20 ppm) to achieve a conductivity of 500 pS/m.

e. Water saturation of the fuel was achieved using the methods described in Appendix B.

f. The saturated fuel was divided into twelve separate containers. Each container was treated with one of the twelve corrosion inhibitors/lubricity improvers listed on QPL-25017-17 at appropriate concentration levels. Identities of the inhibitors along with their dosage rates are shown in Table 3.

TABLE 3. Corrosion Inhibitors and Dosages from QPL-25017-17

CONTAINER #	INHIBITOR NAME	DOSAGE (MG/L FUEL)
1	Apollo PRI-19	22.5
2	DuPont DCI-4A	22.5
3	DuPont DCI-6A	9
4	Ethyl HITEC 580	22.5
5	Nalco 5403	22.5
6	UOP Unicor J	22.5
7	Chemlink IPC 4410	22.5
8	Chemlink IPC 4445	22.5
9	Mobil Mobilad F800	22.5
10	Nalco 5405	11
11	Welchem 91120	22.5
12	Betz Spec-Aid 8021	22.5

g. Each test device was evaluated at 0, 10, 20 and 30 parts per million (ppm) water. The 10 ppm level is the Army limit while the Shell and Exxon are designed to work at the 30 ppm level, the limit for civil aircraft. Water was added to the test fuel using a micro-syringe and a one part per thousand (ppt) water fuel premix described in Appendix C. Additional tests at higher water level were conducted if no response was obtained at the 30 ppm level.

h. The test procedures followed the instructions supplied by the manufactures with the exception of the sample taking for the Aqua-Glo and TMI Accumetric. Both instruments primarily use pad holders that are intended to be installed in pressure lines, e.g., the discharge from a refueling vehicle. As this arrangement was impractical in a laboratory setting a vacuum configuration was assembled as shown in Figure. 1.

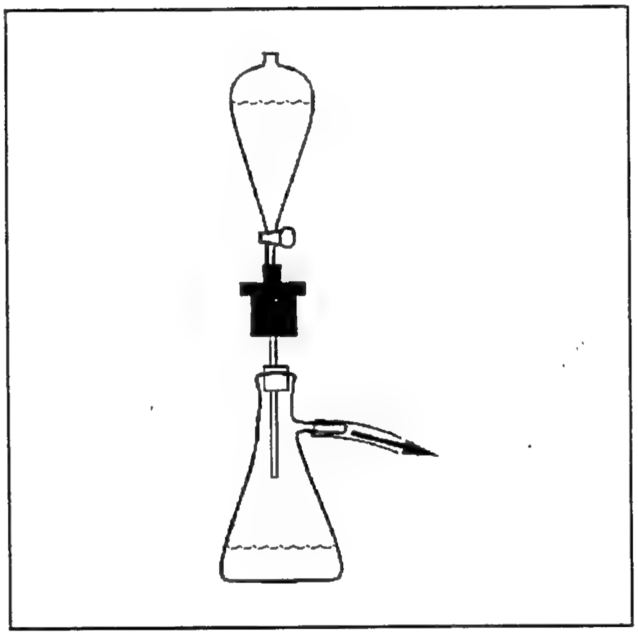

Figure 1. Vacuum Sample Collection Apparatus

i. In addition to the performance tests outlined above, the soldier usability of each kit was also evaluated during the test
period.

RESULTS

Readings of Test Kits

Aqua-Glo and TMI readings indicated in parts per million (ppm) of free water indicated.

Shell and Exxon indicate either change (C) or no change (N/C).

Table 4. Results Obtained Using JP-8 with 0 PPM Water Added to Saturated Fuel

CONTAINER #	AQUA-GLO	TMI	SHELL	EXXON
1	≤1	6	N/C	N/C
2	≤1	3	N/C	N/C
3	≤1	4	N/C	N/C
4	≤1	3	N/C	N/C
5	≤1	2	N/C	N/C
6	≤1	3	N/C	N/C
7	1.0	4	N/C	N/C
8	1.0	3	N/C	N/C
9	1.0	3"	N/C	N/C
10	1.0	3	N/C	N/C
11	1.0	4	N/C	N/C
12	1.0	3	N/C	N/C

Table 5. Results Obtained Using JP-8 with 10 PPM Water Added to Saturated Fuel
(Aqua-Glo indicated reading multiplied by 5 to account for educed sample size in this and all subsequent tests)

CONTAINER #	AQUA-GLO	TMI	SHELL	EXXON
1	≤5	36	N/C	N/C
2	5.0	34	N/C	N/C
3	5.0	38	N/C	N/C
4	≤5	24	N/C	N/C
5	≤5	18	N/C	N/C
6	≤5	17	N/C	N/C
7	≤5	19	N/C	N/C
8	≤5	17	N/C	N/C
9	≤5	14	N/C	N/C
10	5.0	15	N/C	N/C
11	5.0	11	N/C	N/C
12	5.0	10	N/C	N/C

Table 6. Results Obtained Using JP-8 with 20 PPM Water Added to Saturated Fuel

CONTAINER #	AQUA-GLO	TMI	SHELL	EXXON
1	7.5	91	N/C	N/C
2	7.5	51	N/C	N/C
3	7.5	54	N/C	N/C
4	7.5	48	N/C	N/C
5	6.0	28	N/C	N/C
6	6.0	30	N/C	N/C
7	≤5	43	N/C	N/C
8	6.0	35	N/C	N/C
9	6.0	40	N/C	N/C
10	6.0	24	N/C	N/C
11	6.0	33	N/C	N/C
12	5.0	27	N/C	N/C

Table 7. Results Obtained Using JP-8 with 30 PPM Water Added to Saturated Fuel

CONTAINER #	AQUA-GLO	TMI	SHELL	EXXON
1	20.0	110	N/C	N/C
2	15.0	58	N/C	N/C
3	10.0	58	N/C	N/C
4	10.0	35	N/C	N/C
5	7.5	23	N/C	N/C
6	7.5	12	N/C	N/C
7	8.0	33	N/C	N/C
8	10.0	31	N/C	N/C
9	10.0	35	N/C	N/C
10	7.0	29	N/C	N/C
11	10.0	35	N/C	N/C
12	8.0	21	N/C	N/C

Table 8. Results Obtained Using JP-8 with 40 PPM Water Added to Saturated Fuel

(These tests were only performed on the Shell and Exxon kits when no positive results were obtained at 30 ppm)

CONTAINER #	SHELL	EXXON
1	N/C	N/C
2	N/C	N/C
3	N/C	N/C
4	N/C	N/C
5	N/C	N/C
6	N/C	N/C
7	N/C	N/C
8	N/C	N/C
9	N/C	N/C
10	N/C	N/C
11	N/C	N/C
12	N/C	N/C

Table 9. Results Obtained Using JP-8 with 200 PPM Water to Saturated Fuel

(This level of water is sufficient to make the fuel appear hazy. These tests were only performed on the Shell and Exxon Kit when no positive results were obtained at 40 ppm. No further tests were conducted)

CONTAINER #	SHELL	EXXON
1	N/C	N/C
2	N/C	N/C
3	N/C	N/C
4	N/C	N/C
5	N/C	N/C
6	N/C	N/C
7	N/C	N/C
8	N/C	N/C
9	N/C	N/C
10	N/C	N/C
11	N/C	N/C
12	N/C	N/C

Results for the Aqua-Glo and TMI Accumertic are displayed graphically in Figures 2 and 3.

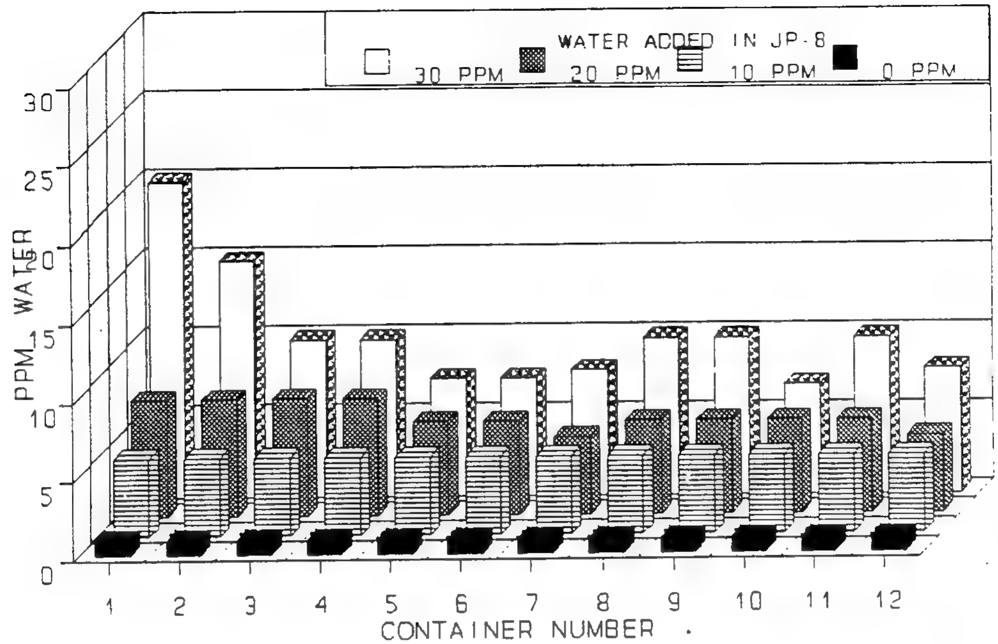

Figure 2. Aqua-Glo Measured PPM Water in JP-8

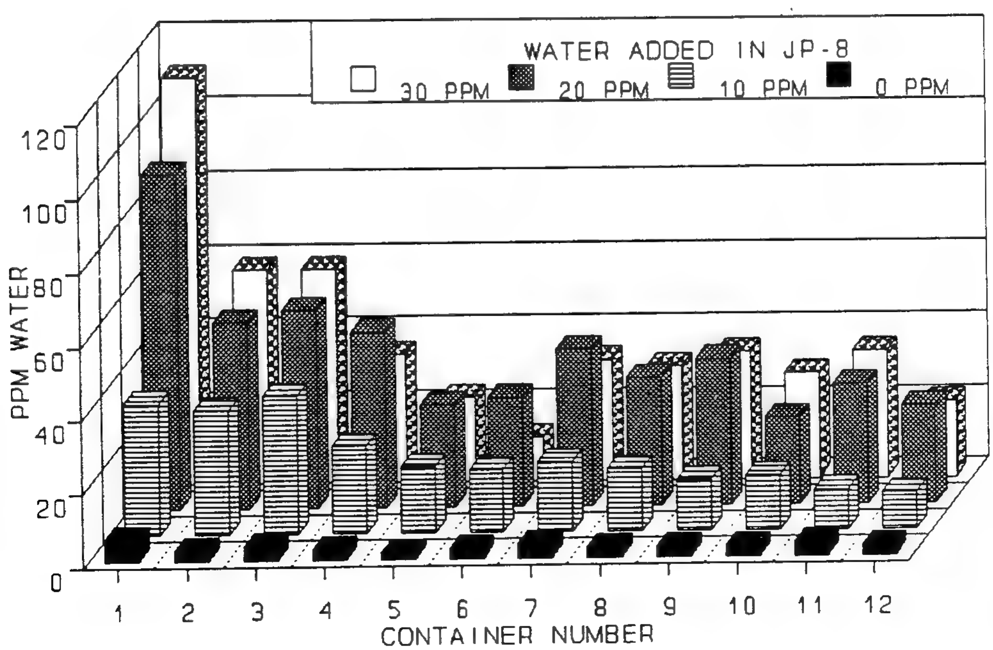

Figure 3. TMI Accumetric Measured PPM Water in JP-8

Soldier Usability

Speed of response. All of the instruments responded quickly, when they did respond. The Aqua-Glo takes a little longer preparation time due to the necessity to blot the membrane before placing it in the instrument.

Readability. The TMI, having a digital display, is much easier to read than the Aqua-Glo.

Use of arctic mittens. The instruments were basically operable while wearing arctic mittens with the exception of the Aqua-Glo. The button that turns on the u.v. light could not be reached.

Use under reduced lighting. The color change in the Exxon Hydrokit could not be discerned in reduced or red lens lighting. In order to effect any color change in the Exxon and Shell kits it was necessary to run them with straight water.

Ruggedness. No drop test was conducted. It is assumed that the u.v. lamps in the Aqua-Glo and TMI are the only breakable components. However both instruments are protected by heavy fiberboard cases. The Shell and Exxon kits are all plastic and assumed to be practically unbreakable.

Section 3 Discussion & Conclusions

DISCUSSION

a. The measured values obtained from any of the test kits cannot be considered an accurate measure of free water. At best, it is an indication of the amount of water that was added to fuel that was presumed to be saturated. There is no way to reliably measure actual free water in the laboratory or in the field.

b. The Shell Water Detector Kit and the Exxon Hydrokit did not provide any usable data in this evaluation.

c. The Gammon Aqua-Glo gave the most consistent readings although somewhat lower then expected.

d. The TMI Accumetric readings were somewhat more inconsistent and, in most cases, higher that expected.

e. The TMI Accumetric ranks high in readability and soldier usability.

f. There is concern over the quality control of the water detector pads. While all the pads used in this test were recently manufactured and, presumably, of uniform quality there is no way to assure uniform quality in the field.

g. At least one of the corrosion inhibitors (Apollo PRI-19) seemed to affect the output of both the Aqua-Glo and TMI Accumetric to give higher than expected readings.

CONCLUSIONS

a. The relationship between type of corrosion inhibitor and effectiveness of the Shell Kit could not be demonstrated. There may be some affect of one of the corrosion inhibitors on the readings of the Gammon Aqua-Glo and the TMI Accumetric.

b. There is a need for a proven calibration procedure for water-in-fuel measuring instruments and test kits.

c. Based on the data generated in this evaluation, the Army should continue to use the Gammon Aqua-Glo as a field test kit.

d. There is a need for a quality control program for water detector pads. This could include stated expiration dates or even a Qualified Products List (QPL) for vendors.

Section 4 Definitions

FREE WATER

Any water in fuel that is not dissolved (solubilized). Such water may be separated (sitting on the bottom) or suspended.

SUSPENDED WATER

Water droplets (discontinuous medium) that are suspended in fuel (continuous medium) to form a homogeneous mixture. At higher water levels the mixture will appear hazy.

WATER SATURATED FUEL

Fuel that has the maximum amount of water dissolved (solubilized) in it such that any additional water will come out as free water. Solubilization of water in fuel is highly dependent on temperature and the levels of aromatics in the fuel.

Section 5 References

1. Letter, ATSM-PWD-P, 15 April 1992, SUBJECT: Simplified Water Detection Test for Jet Fuels.

2. *Annual Book of ASTM Standards*, Volume 05.02. "Petroleum Products and Lubricants (II)", 1992, pp 320-324, pp 641-643.

3. *Annual Book of ASTM Standards*, Volume 05.03, "Petroleum Products and Lubricants (III)", 1992, pp 165-179.

4. U.S. Army Field Manual, FM 10-68, *Aircraft Refueling*.

5. Military Specification MIL-I-25017E, *Inhibitor, Corrosion/Lubricity Improver, Fuel Soluble*, 15 June 1989.

6. Qualified Products List (QPL) 25017-17, *Inhibitor, Corrosion/Lubricity Improver, Fuel Soluble*, 15 March 1994.

7. Military Specification MIL-T-83133D, *Turbine Fuels, Aviation, Kerosene Types, NATO F-34 (JP-8) and NATO F-34*, 29 January 1992.

Appendix A Method for Clay Filtration of Fuel

A glass funnel with a 38 mm (1.5 in) sintered glass bottom was used to hold approximately 250 mL of filtration clay identified as Georgia Red Clay. A vacuum pump was used to pull the fuel through the clay. Approximately 250 mL (150 g) of clay was required to completely clean one liter of fuel. The cleanliness level was measured by use of ASTM D 3602, *Water Separation Characteristics of Aviation Fuels (MicroSep)*, which indicates the levels of surfactants in the fuel.

Appendix B Method for Water Saturation of Fuel

This method is based on the procedure used by Gammon Technical Products.
A five gallon glass jug was carefully filled with approximately two liters (one-half gallon) of distilled water so that no water droplets would cling to the sides of the jug above the water level. The water level was sufficient to cover the entire bottom of the jug at its maximum diameter. One or more large sheets of Whatman filter paper were inserted in the jug so that the bottom of the paper was immersed in the water. Approximately sixteen liters (four gallons) of clean dry fuel was slowly poured over the water so as to avoid intermingling of the water and fuel. The top part of the filter paper was manipulated so as to protrude into the fuel layer. The paper acted as a wick to bring water up into the fuel layer. The air space above the fuel was kept water saturated by means of a vent tube leading to a water bottle. A siphon was used to remove the saturated fuel. The setup is shown in Figure. 4. The fuel water combination was left in the jug one day for each four liters (one gallon) of fuel.

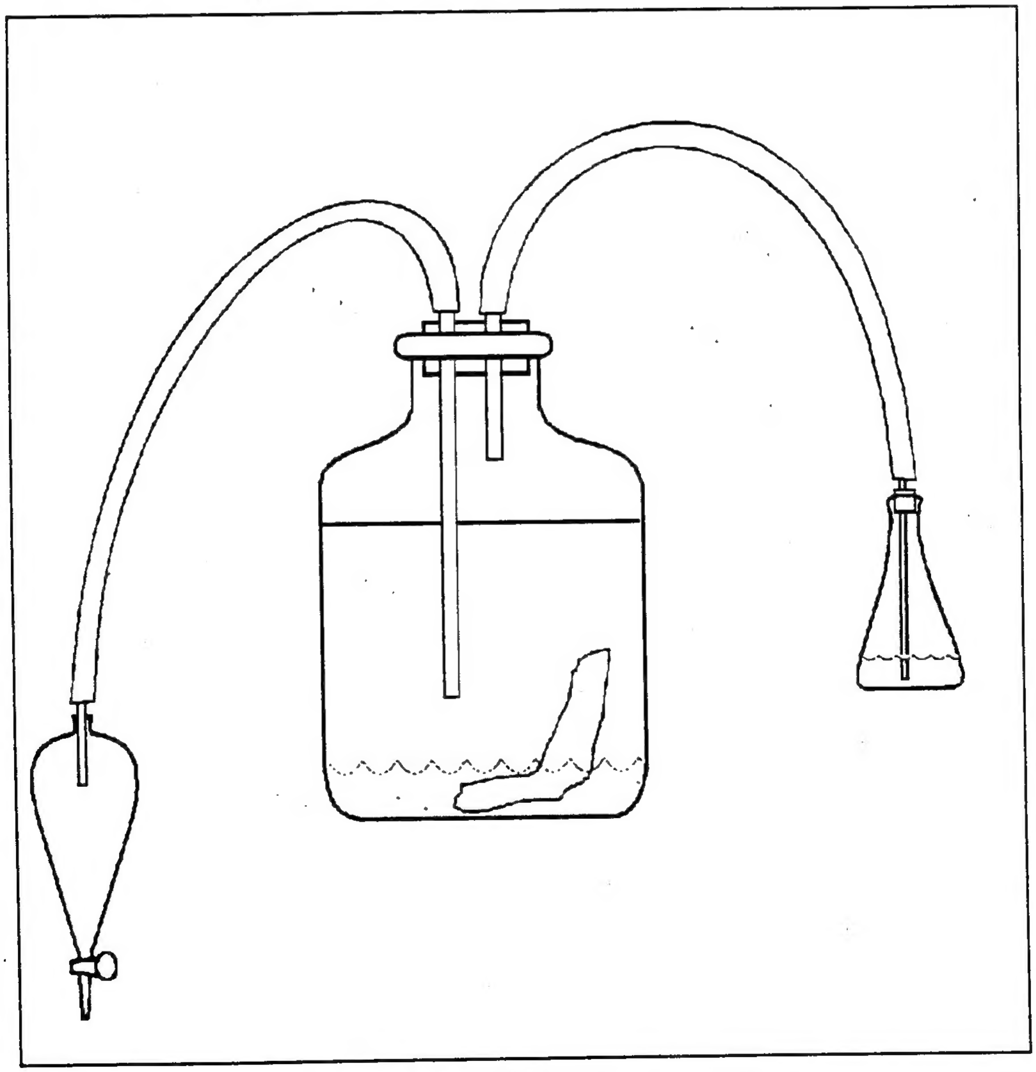

Figure 4. Fuel Saturation Aparatus

Appendix C Method for Preparation of Fuel Water Premix

Approximately 500 mL of JP-8 fuel containing Fuel System Icing Inhibitor (FSII) and Static Dissipator Additive (SDA) was mixed with one part per thousand (1000 ppm) of distilled water. A microsyringe was used to add the water. The mixture was blended in a stainless steel Waring Blendor for 8 to 10 seconds. Just before the mixture had to be used it was blended for another 2 seconds. This concentrated premix was used to add the water to the fuel at prescribed ppm levels to each of the containers.

Distribution for TARDEC Technical Report 13613

DEPARTMENT OF THE ARMY

HQDA
1 ATTN DALO TSE
1 ATTN DALO SM
PENTAGON
WASHINGTON DC 20310-0103

SARDA
1 ATTN SARD TL
PENTAGON
WASHINGTON DC 20310-0103

CDR AMC
1 ATTN AMCRD S
5001 EISENHO WER AVE
ALEXANDRIA VA 22333-0001

TARDEC
1 ATTN AMSTA R
1 ATTN AMSTA RG
12 ATTN AMSTA RBF
6 ATTN AMSTA RBW
WARREN MI 48397-5000

CDR ARMY TACOM
1 ATTN AMSTA FT
1 ATTN AMSTA MT
1 ATTN AMSTA KL
WARREN MI 48397-5000

CDR ARO
1 ATTN AMXRO EN(D MANN)
RSCH TRIANGLE PK
NC 27709-2211

CDR ARMY ATCOM
1 ATTN AMSAT I ME (L HEPLER)
1 ATTN AMSAT I LA (V SALISBURY)
1 ATTN AMSAT R EP (V EDWARD)
1 ATTN AMSAT I IO
1 ATTN AMSAT I MA
4300 GOODFELLOW BLVD
ST LOUIS MO 63120-1798

CDR AVIA APPL TECH DIR
1 ATTN AMSAT R TP (H MORROW)
FT EUSTIS VA 23604-5018

CDR APC
1 ATTN SATPC Q
1 ATTN SATPC QE (BLDG 85 3)
NEW CUMBERLAND
PA 17070-5005

1 PETROL TEST FAC WEST
BLDG 247 TRACEY LOC
DDRW
P O BOX 96001
STOCKTON CA 95296-0960

CDR LEA
1 ATTN LOEA PL
NEW CUMBERLAND
PA 17070-5007

CDR ARMY TECOM
1 ATTN AMSTE TA V
1 ATTN AMSTE TC D
1 ATTN AMSTE EQ
APG MD 21005-5006

PROJ MGR PETROL WATER LOG
3 ATTN AMCPM PWL
4300 GOODFELLOW BLVD
ST LOUIS MO 63120-1798

CDR ARMY QM SCHOOL
3 ATTN ATSM CD
1 ATTN ATSM PWD
FT LEE VA 23801-5000

CDR ARMY AVIA CTR
1 ATTN ATZQ DOL M
1 ATTN ATZQ DI
FT RUCKER AL 36362-5115

PS MAGAZINE DIV
1 ATTN AMXLS PS
DIR LOGSA
REDSTONE ARSENAL
AL 35898-7466

DEPARTMENT OF THE NAVY:

OFC OF NAVAL RSCH
1 ATTN ONR 464
800 N QUINCY ST
ARLINGTON VA 22217-5660

CDR
NAVAL RSCH LABORATORY
1 ATTN CODE 6181
WASHINGTON DC 20375-5342

1 CDR
NAVAL PETROLEUM OFFICE
CAMERON STA T 40
5010 DUKE STREET
ALEXANDRIA VA 22304-6180

CDR
NAVAL AIR SYSTEMS CMD
1 ATTN AIR 53623C
1421 JEFFERSON DAVIS HWY
ARLINGTON VA 22243-5360

DEPARTMENT OF THE NAVY/U.S MARINE CORPS:

HQ USMC
1 ATTN LPP
WASHINGTON DC 20380-0001

1 PROG MGR COMBAT SER SPT
MARINE CORPS SYS CMD
2033 BARNETT AVE STE 315
QUANTICO VA 22134-5080

CDR
MARINE CORPS SYS CMD
1 ATTN SSE
2033 BARNETT AVE STE 315
QUANTICO VA 22134-5010

DEPARTMENT OF AIR FORCE:

AIR FORCE WRIGHT LAB
1 ATTN WL/POS
1 ATTN WL/POSF
1790 LOOP RD N
WRIGHT PATTERSON AFB
OH 45433-7103

1 SA ALC/SFT
1014 ANDREWS RD STE 1
KELLY AFB TX 78241-5603

DEPARTMENT OF DEFENSE:

DEFENSE FUEL SUPPLY CTR
1 ATTN DFSC Q BLDG 8
CAMERON STA
ALEXANDRIA VA 22304-6160

12 DEFENSE TECH INFO CTR
CAMERON STA
ALEXANDRIA VA 22304